An On-Line Integrated Control System for Reducing Coal Costs and Coal-Related Emissions: Coal Blend Automation System (CBAS)

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Introduction

In 1995, TransAlta Utilities and Dairyland Power agreed to participate in a project funded by the U.S. Department of Energy to demonstrate a power plant optimization software product developed by Praxis Engineers, Inc. The product, the Plant Environmental and Cost Optimization System (PECOS™), considers the power plant in its entirety from coal receipts and yard management to solid by-products and emissions. Its basic goal is to minimize the controllable costs of power generation. PECOS does so by performing an on-line analysis of all operations and their co-optimization to achieve a minimum generation cost. The software acts as an advisor to the plant operators and computes settings that achieve this goal. A general schematic of PECOS is given in Figure 1.

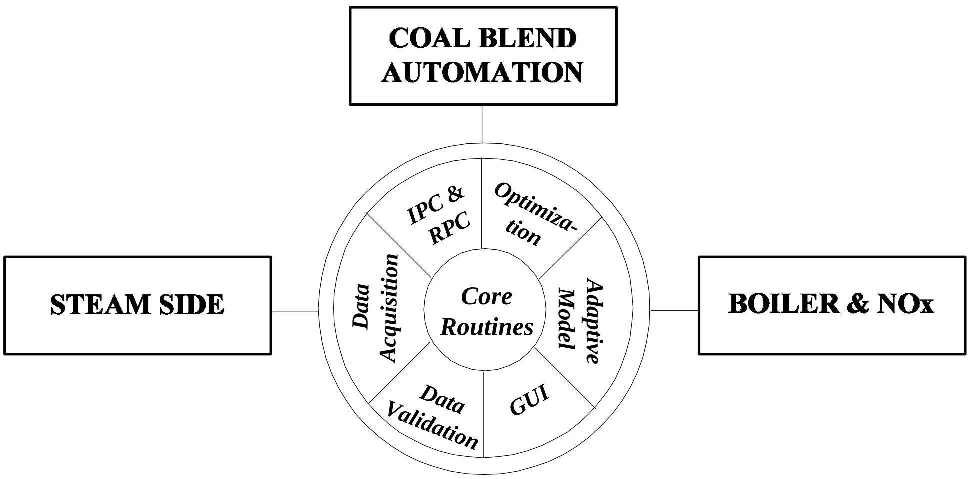

Figure 1. Schematic of PECOS applications modules

PECOS consists of four modules:

1. The core routines represent the functions of data management, adaptive capability, and overall optimization.

2. The Coal Blend Automation System (CBAS™) is responsible for managing all stockpiling and blending actions in the yard. Its objective is to minimize fuel-related costs and to deliver coal of a predetermined quality to the burners at all times.

3. The Boiler and NO_x Control System (BANCS™) is responsible for all settings related to boiler operations and NO_x emissions. Its basic objective is to minimize generation costs while taking into account the coal quality, equipment availability, load requirements, ash disposal/sales, and all emissions, i.e., NO_x, SO_2, CO, CO_2, and opacity.

4. The Steam Cycle Optimization System (SCYCLOPS™) is responsible for all settings related to steam cycle operations and equipment, including turbines, feedwater heating, condenser back pressure, and steam extraction.

This paper focuses on CBAS, which can be installed either by itself or along with the other modules of PECOS.

CBAS Features

CBAS represents a departure from the normal coal blending practices at utility yards that either use fixed blends or use their coals as they arrive, even when such practices have deleterious economic and operational consequences. CBAS, in contrast, dynamically changes blends in real time to respond to shifting conditions and needs.

The main features of CBAS are that it:

- Controls and predicts coal quality at the burners
- Advises operators on optimal blends and can change the quality of blends as the conditions require
- Tracks all coal in the system
- Has a built-in database that allows correlation of coal quality with boiler performance.

The first installation of CBAS at TransAlta Utilities' Keephills Plant is now complete and the software is in operation. The installation at Dairyland Power's Genoa Station is scheduled for the second quarter of 1998.

Background

Coal is the most important fuel in the generation of electricity, accounting for between 55 and 60% of the power produced in the United States and Canada. It is available in great abundance from indigenous sources and there are no problems associated with its long-term supply. In the past, because of the regulated business environment in which utilities operated, coal was viewed as a necessary evil and was always treated as a "pass through" cost. Thus, a knowledge of coal quality and its impacts on boiler operations had little economic or technical interest for utilities. However, this perspective started to change with early legislative requirements for the control of SO_2 emissions. The legislative agenda has now advanced to include NO_x and particulate emissions and necessitates a clear understanding of the interactions between coal quality and the process of combustion. Further, the economic aspects of coal utilization are also changing. The main driving force behind this change is the transition utilities are undergoing from a regulated to a competitive business environment where costs must be controlled and reduced. Since coal accounts for nearly 70% of the O&M costs of electricity generation, it provides an obvious opportunity for this purpose. The goal of reducing costs can be achieved by procuring lower-cost fuels, by avoiding coal quality-related operational problems, and by improving the overall efficiency of coal utilization in the plant.

Advantages of Coal Blending

Real-time control for blending coals can assist utilities in the face of greater competition and stricter emission regulations. If a power plant adopts a dynamic approach to coal blending, i.e., it changes the as-fired blends continuously to adjust to changing conditions such as load, emissions, opacity, coal availability, and expected coal deliveries, it will reduce its fuel-related costs significantly. This approach requires on-line tracking of coal data such as sources, flow rates, quality parameters, location in the piles, bunker levels, and expected deliveries. However, the collection and management of these data electronically are relatively cheap and can be implemented with no technical innovation.

There are a number of ways in which dynamic blending of coals can improve efficiency and decrease costs. Plants blending their boiler feed from a number of coals can maximize the use of the cheapest coal whenever conditions permit; utilities can rationalize the use of coals to avoid overusing premium coals and under using problem coals; lastly, they can deliberately increase purchases of cheaper spot-market coals knowing that they can mitigate the attendant problems by controlled dynamic blending. The economic consequences of the dynamic blending approach are considerable, and plants can significantly reduce operating costs by its use.

Typical Utility Yard and Related Issues

In order to blend coal successfully and to accurately control and predict its quality at the burners, a number of issues must be addressed. These issues may be site specific but are usually similar for most plants. A typical coal utility yard receives its coal(s) from multiple sources and stores them in semi-segregated piles or silos. Coal is withdrawn from the piles or silos and is loaded into bunkers supplying the mills that typically have capacities ranging from 4 to 48 hours. For such systems, the following operations are necessary to perform effective coal blending:

- The quality and characteristics of each type of coal used should be known. It is assumed that the quality of each shipment is known from vendor-supplied analyses or from independent sampling.

- Information concerning the loading of each coal into the piles or yard silos must be available including the time, amount, location and type of coal loaded.

- Data on coal sources, conveyer weigh scales, tripper locations, bunker levels, and mill feed rates must be available.

- Flow patterns in the piles, silos, and bunkers must be understood and modeled for successful control and prediction of coal quality at their outputs.

- Relevant boiler parameters must be available to analyze and correlate changes in boiler behavior in response to changes in coal quality. Necessary boiler parameters are dependent on the particular site and can include stack emissions (SO_2, NO_x and opacity), load, and temperatures associated with soot and slag buildup on furnace and boiler surfaces.

Most of the items listed above are generally readily available at existing coal power plants and involve only collection and tracking of data. The key problem that must be solved if dynamic blending is to be usefully employed is the modeling of the flow of coal through the bunkers, silos, and piles. This has been done by Praxis Engineers with its Silo Flow™ Model, which is described in the following section.

Silo Flow Modeling

It is relatively simple to track the sequence, quality, and tonnage of coal being loaded into piles, silos, or bunkers. However, predicting the quality of the coal as it is discharged by the silos is a complex undertaking and depends to a large extent on the geometry of the silo, bunker, or pile as well as its recent operational history.

There are two distinct types of coal flow in a bunker or silo: mass flow and funnel flow. In the case of mass flow, all of the coal flows evenly with no "dead zones," so that coal at the bottom of the bunker comes out first, while the coal at the top of the bunker comes out last. There is little mixing between coals at different layers in the bunker, although the center of the bunker, directly above the feeder, moves at a faster rate than the sides, causing a slight depression in the center.

In the case of funnel flow, on the other hand, there are dead zones along the bunker walls where the coal does not flow. Coal flows only in a conical region, called the "active zone," extending upwards from the feeder. From the top of the bunker, the flow pattern looks similar to a volcano or a "rathole." The dead zone is typically contained within an angular region in the silo or bunker, and the angle characterizing the zone is called the incipient angle. For funnel flow bunkers, it is possible that the coal added to the top of the bunker will rapidly exit the bunker. Mixing occurs because the coal in the dead zones along the walls periodically falls into the active zone, and the ratio of velocity at the center to the velocity at the perimeter of the active zone is typically high.

A diagram illustrating the two bunker flow types and their inherent differences is shown in Figure 2. The principal factors that dictate whether a bunker has mass or funnel flow are its geometry and the properties of the coal itself. Bunkers with long gradually tapered sections are more likely to produce mass flow, while bunkers with relatively short tapered sections can produce funnel flow. Frequently, in practice, bunkers are termed "mass flow" if they seldom plug or form stationary ratholes. Such bunkers can actually be funnel flow in performance.

Characterizing the mixing and flow patterns in the bunkers is critical to accurately tracking the coal from the yard to the burners. A typical assumption is that the bunker produces mass flow or first-in first-out (FIFO) behavior, which can lead to significant errors in the assumed coal properties at the burners, as depicted in Figure 3. The figure shows the discharge of four different coals that have been loaded into a silo in sequence. The ash contents of these coals are assumed to be 10, 12, 14, and 16% respectively. The silo is unloaded over a period of 40 hours. Mixing between layers caused by the difference in velocities from the center to the walls produces significant deviation from expectations based on FIFO. While in the case of mass flow this difference is fairly small, for funnel flow it can be significant. Under these conditions, it can be demonstrated that some portions of the coal loaded first into the bunker are the last to be discharged. This accounts for the reduction in the ash content near the end of the discharge cycle as shown in the figure.

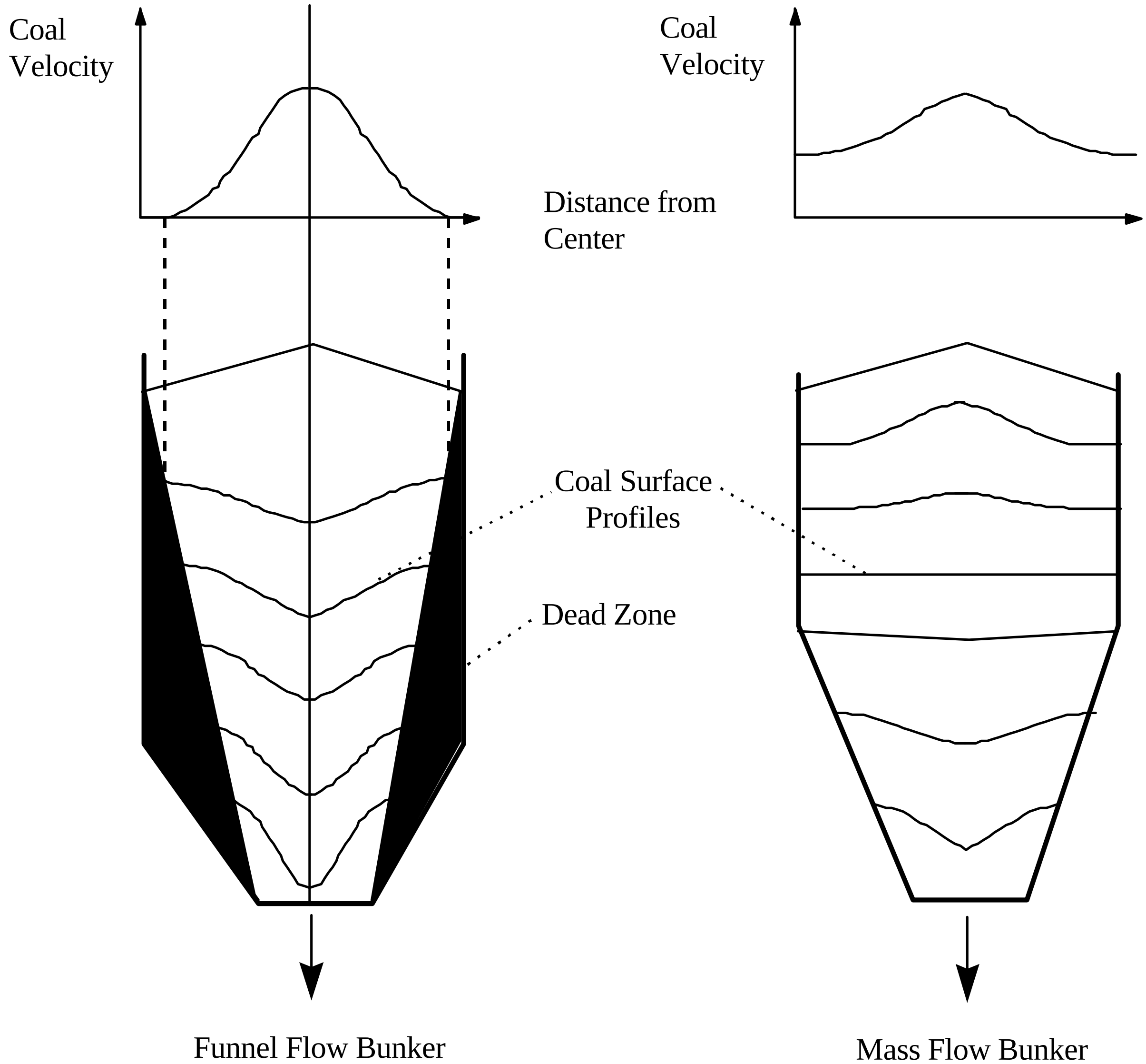

Figure 2. Depiction of characteristic differences in coal flow patterns between mass and funnel flow bunkers

The Silo Flow Model is capable of on-line operation and can deal with simultaneous loading and unloading. It can model both mass and funnel flow silos as well as flow in free standing coal piles. The main inputs used in the modeling of the coal flow are silo or pile geometry, the location of the load-in point(s) and the location of the discharge points, the angle of repose, the incipient angle, and coal density. The model maintains an ongoing mass balance that can be periodically adjusted by automatically using information such as bunker level indicators or high/low level alarms.

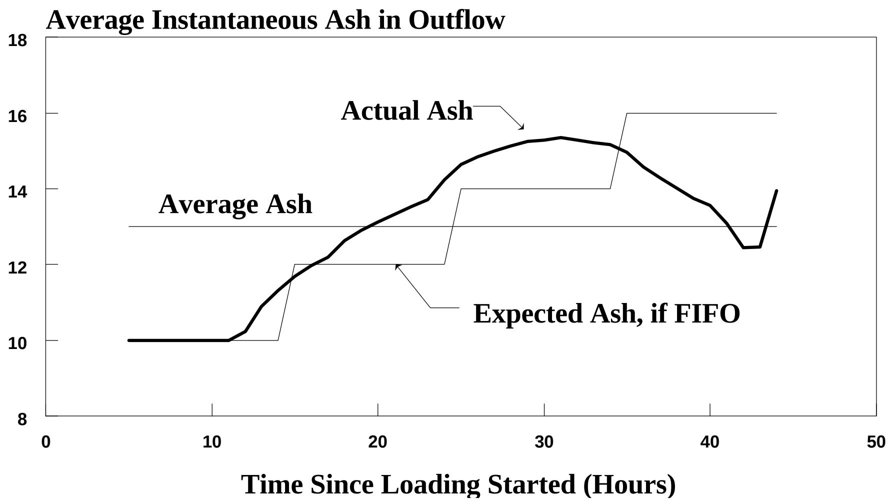

Figure 3. Typical silo output quality variation illustrating deviation of actual flow from FIFO flow

The model is used in CBAS in a number of ways. Its obvious use is for predicting the sequence of coal quality output. However, its real value lies in its ability to advise the operators on blend decisions in the yard to achieve desired profiles of coal feed to the boilers by taking advantage of the residence time in the bunkers. Examples of such uses include:

- Increased proportions of cheaper coals during low-load periods
- Blending coals to achieve compatible feeds to preempt specific problems such as slagging, SO_2 and NO_x emissions, and opacity
- Devising load-in and load-out strategies to minimize the impacts of unexpected changes in coal quality
- Ensuring that “good” coals are always available to counteract the effects of “problem” coals
- Correlating problems in the boilers to specific coals or coal blends.

Coal Blend Automation System (CBAS) Architecture

The CBAS architecture is shown in Figure 4. CBAS consists of the following software modules, described in greater detail below:

- CBAS Client user interface
- DASMod
- EventMan
- CoalTrack
- OptiMix

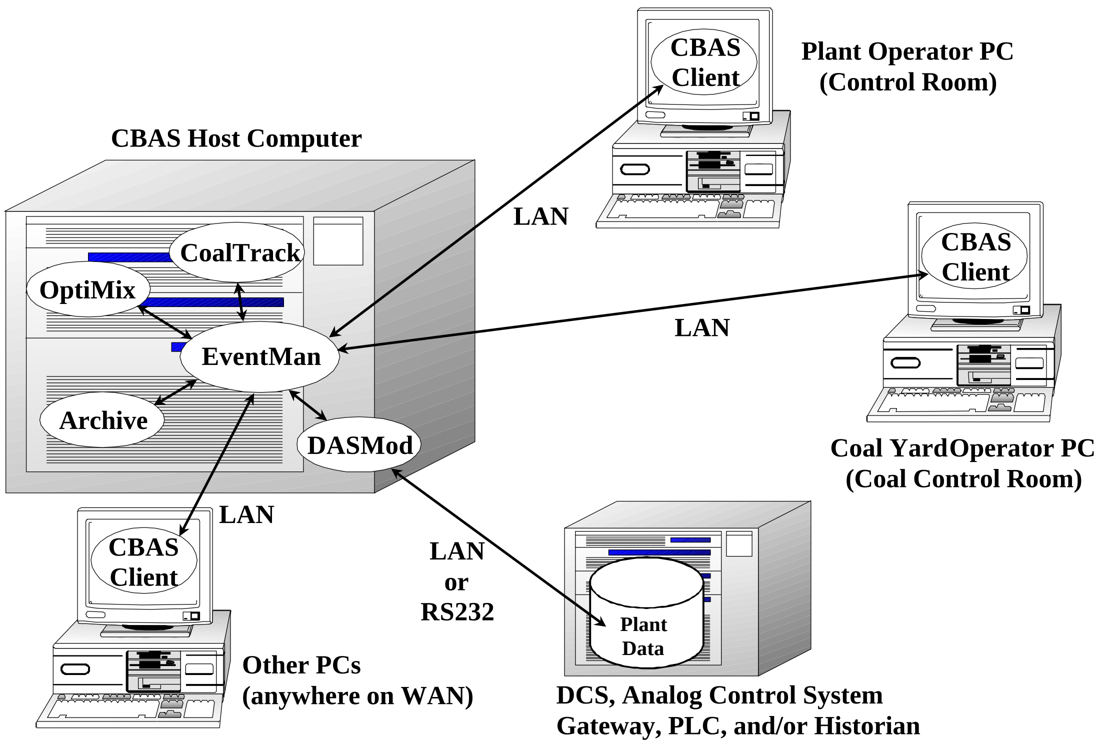

Figure 4. CBAS architecture

CBAS Client User Interface

CBAS is a distributed, client-server software system whose users can be located anywhere on the utility local or wide area networks. The primary users are the coal yard operators and the boiler control room operators who use advice from CBAS in making the least-cost use of available coals. Other key users include fuel department engineers, plant engineers, and managers. These users run the CBAS Graphical User Interface or "Client" program on their own PCs. The Client program gets continual data updates from the CBAS "Server" and formats these data for display.

It also accepts data inputs and computational requests from the user and passes them on to the CBAS Server for action.

All other CBAS computations and functions are performed on the CBAS Host Computer, a dual-processor Pentium PC running Windows NT.

DASMod

The DASMod communicates via RS-232 or LAN connections with the plant data sources to retrieve near-real-time operations data approximately every 10 seconds. Modules are available for communication with a variety of typical plant data sources, such as control system gateways (e.g., Bailey CIU and Westinghouse SIU) for both analog and digital control systems, PLCs, and data historians such as OSI's PI™ Archive and NUS' P-Max/R*Time™ packages.

EventMan

The EventMan module, or "event manager" manages all the information traffic flow between the other modules of CBAS. It continually retrieves real-time plant data from the DASMod, validates the data, sends any desired data outputs back to the plant control system via DASMod, accepts user inputs from the Client interface over the LAN or WAN, supplies all of the active Client Interfaces on the LAN/WAN with continually updated data about plant operations and recommended control actions, distributes data and information requests between the computational modules of CBAS, and archives selected data for use in later analyses. It ensures that information flows are synchronized and timely.

CoalTrack

The CoalTrack module contains the Praxis simulation modules for coal handling equipment, silos, bunkers and coal piles. It uses the real-time operations data for weigh scales, conveyor status, flop gate positions and the like, along with the Silo Flow Model which models bulk materials flow in piles and silos to track the flow of coal from receipt, through piles, conveyors, and silos all the way to the burners. Users assign coal identifiers and quality data to the coal lots at receipt, and the CoalTrack module is then able to calculate the quality of all coal throughout the system, and to predict the coal flows out of the piles and silos several hours in advance.

OptiMix

The OptiMix module implements the Model Predictive Control (MPC) strategy. OptiMix uses several types of models, either alone or in conjunction with one another depending on the particular application, such as mathematical models, fuzzy-neuro models, and the Silo Flow Model, and converges at an optimum solution for a case-specific prediction horizon. The strength of this module lies in its accuracy and flexibility, both in modeling and in optimization. The optimization techniques in CBAS use conventional methods, fuzzy logic-based algorithms, and Genetic Algorithms (GA). Based on adjustable constraints and requirements, OptiMix computes the best pile management, coal blending, and bunker feed actions for the coal yard and boiler operators. These recommended actions are sent to the Client Interface via the EventMan module.

The control actions recommended by OptiMix fall into two main categories, either or both of which may be installed at a particular site: 1) yard or pile management, and 2) dynamic blend management of the coal quality sent to the bunkers or silos feeding the boiler. The application at Keephills emphasizes pile management while that at Genoa is based on dynamic blend management.

The objective of yard management is to produce a blend from the yard that:

- Meets the plant requirements over a user-defined time span in terms of emissions potential, heating value, and low slagging potential
- Is sustainable in terms of the pile contents and anticipated deliveries
- Operates within equipment-related constraints
- Maintains the correct pile segregation by creating “space” to accommodate the new deliveries and placing receipts in their correct space.

The objective of dynamic blend management is to create a varying blend to the bunkers which uses the smallest possible amount of high-cost fuels at all times, while still meeting operational constraints such as providing high-enough heating value to meet the current load demand, and avoiding operational problems such as slagging and excess emissions.

As an example, the trade-offs between use of low-cost, low-Btu fuels and meeting load demands are handled automatically by CBAS. Figure 5 illustrates projected savings based on the conditions at Genoa in both fuel costs and increased power sales from using dynamic blending, compared to the best available fixed blend ratio. In this instance, the plant was using a fixed blend containing 70% Power River Basin (PRB) coal that did not have high enough heat content to meet the peak load demand. By dynamically changing the coal blends, gains were made in both aspects, i.e., the use of cheaper coal was increased and more power was produced for sale.

CBAS Customization

CBAS is an object-oriented software system, developed in C++, and all of its modules are built with a view to simplifying calibration at a specific site. For example, the coal tracking system configuration for a new coal yard is customized by listing the handling system objects present (flop gates, conveyors, silos, etc.) and their characteristics such as geometry or conveyor speed. Tag IDs are also listed to connect on-line plant data with the model variables.

The calibration of the Silo Flow Model is relatively simple and requires only about one week of testing in the field.

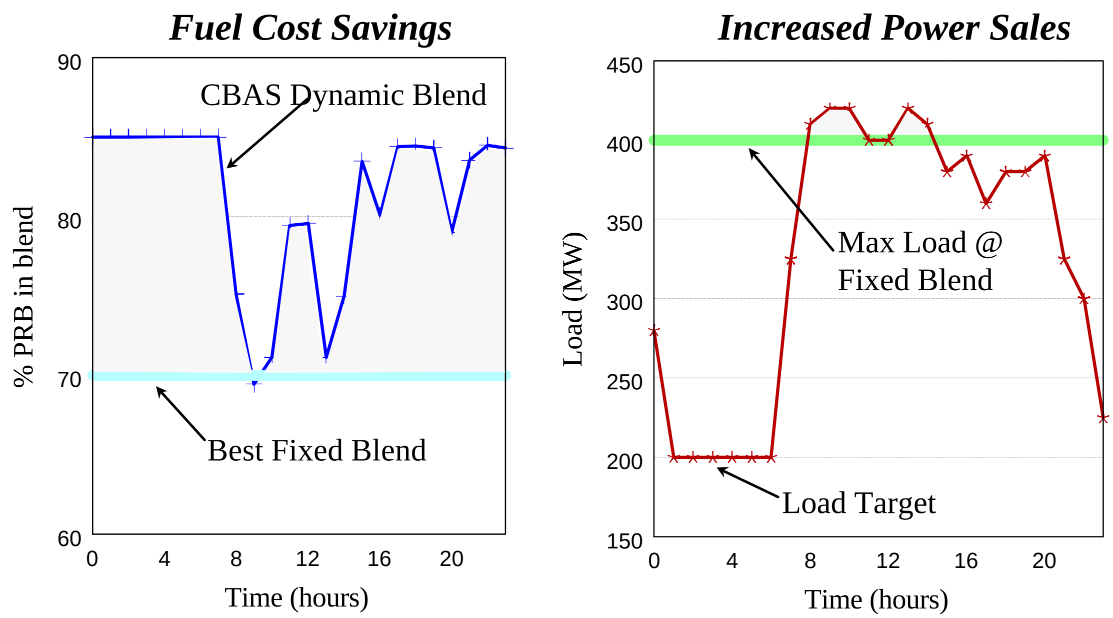

Figure 5. CBAS dynamic blend results in both fuel cost savings and ability to meet maximum loads

CBAS Installations and Case Studies

Keephills Plant

The first application of CBAS is at TransAlta Utilities' Keephills Plant. The initial installation and testing of the software started in March 1996. At first, only the data acquisition modules were installed. The final product was installed in October 1996 and operator training was completed by December. By January 1997, the plant had acquired sufficient confidence in CBAS to let it replace the previous methods of coal pile management.

The issues at Keephills were related to the differences in the quality of coal from the various seams from TransAlta's captive mines at the site. Some of these coals tended to increase opacity at the stack to undesirable levels while others produced relatively low opacities. A previous study had demonstrated that judicious blending of these coals would eliminate a large proportion of the opacity-related incidents and the ensuing loss of power generation due to derates.

Because of the varying proportions of coals mined from each seam, their changing qualities, variable scheduling, limited space in the coal yard, and non-linear ESP efficiency dynamics, it was clear that dynamic blending was the only solution. This represented an ideal opportunity for the use of CBAS.

A schematic of the Keephills coal yard, from the CBAS users interface, is shown in Figure 6. The total capacity of the coal pile is 70,000 tonnes, of which about 30,000 tonnes is live. The plant uses approximately 10,000 tonnes of coal in a 24-hour period, and an equal amount of coal is added to the stockpile each night. There are 18 feeders located under the stockpile that load coal into 10 bunkers that, in turn, feed the two boilers at the site.

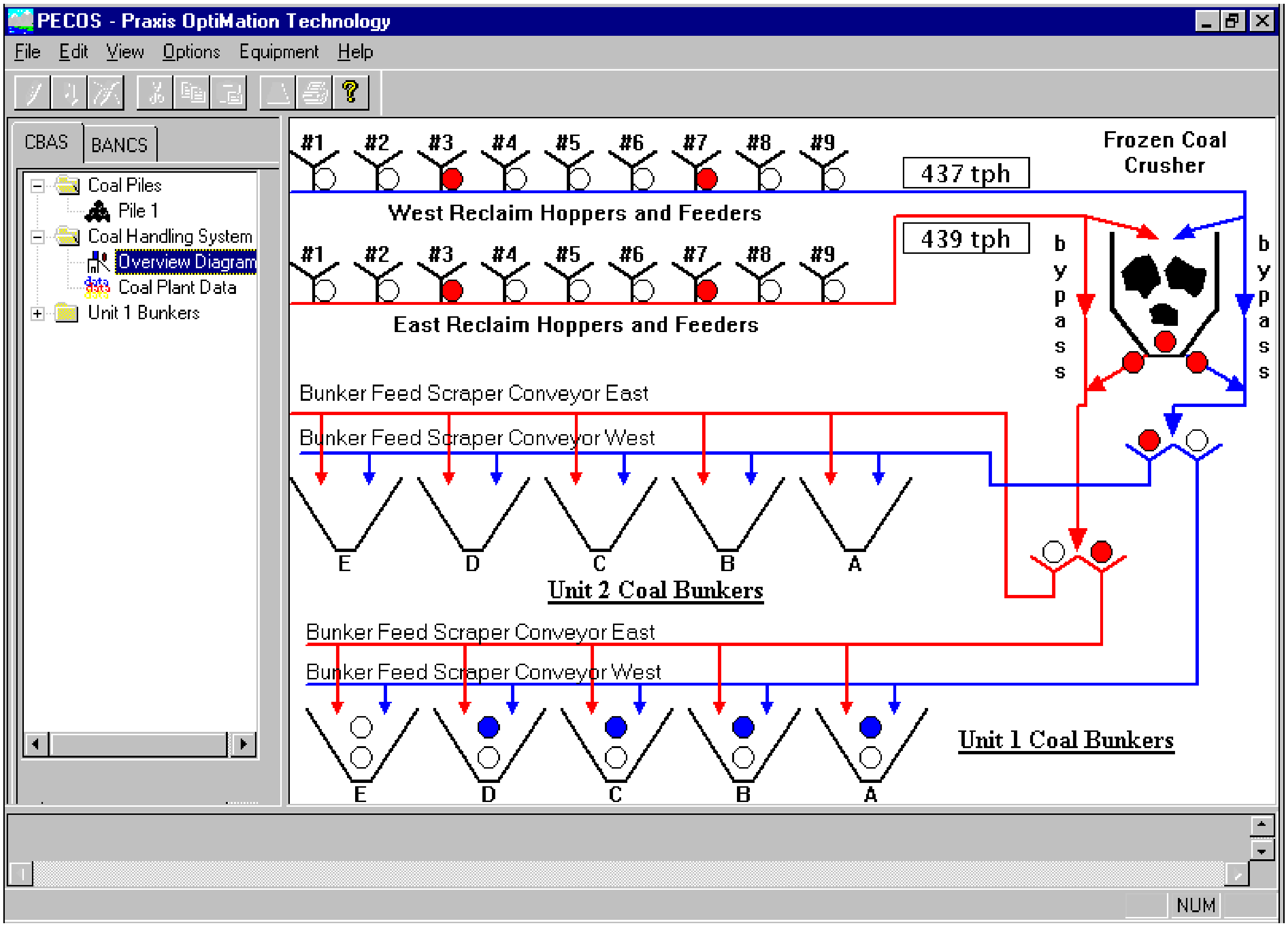

Figure 6. CBAS screen capture showing a typical power plant coal yard layout

CBAS advises the plant operators on withdrawal of coal from the pile, taking into account the following:

- Expected coal deliveries
- Seams in the stockpile and coal flow as a function of time from the stockpile
- Plant conditions, e.g., load, opacity, and emissions
- Need to maintain “low-opacity” coals in reserve
- Time and space constraints of the system
- Mechanical constraints and status of the equipment

- ESP dynamics.

Keephills has been implementing coal blending strategies devised by Praxis for over a year, during which opacity derates were significantly curtailed, saving the plant about $1.5 million in operating costs. CBAS represents the next step in automating the process, providing the coal blend advice on-line in real time, giving the operators more accurate and more timely information. CBAS should produce even tighter control and further reduction in opacity-related costs in addition to providing Keephills with the flexibility to adapt their coal blending strategy to varying coal types and goals.

Genoa Station

The installation at Dairyland Power's Genoa Station will be completed during the second quarter of 1998. The plant is blending a Powder River Basin (PRB) coal with an eastern coal and, due to the low price of the former, would like to maximize its usage. However, the acceptable amount of PRB coal in the blend decreases as the load increases. If fuel costs are to be minimized, the blend must always just conform to the load, i.e., a blend containing the maximum permissible PRB component should be used when load is changing up or down. CBAS achieves this by calculating the blends needed at the burners from the load curves and using the Silo Flow Model and CoalTrack to assure that they will be available as necessary.

Typical examples of daily load curves are shown in Figure 7. The ability of CBAS to deliver the right coal to the boilers is shown in Figure 8, illustrating the way in which CBAS leads and lags blend control in the yard in order to time the delivery of the correct blend to the boilers.

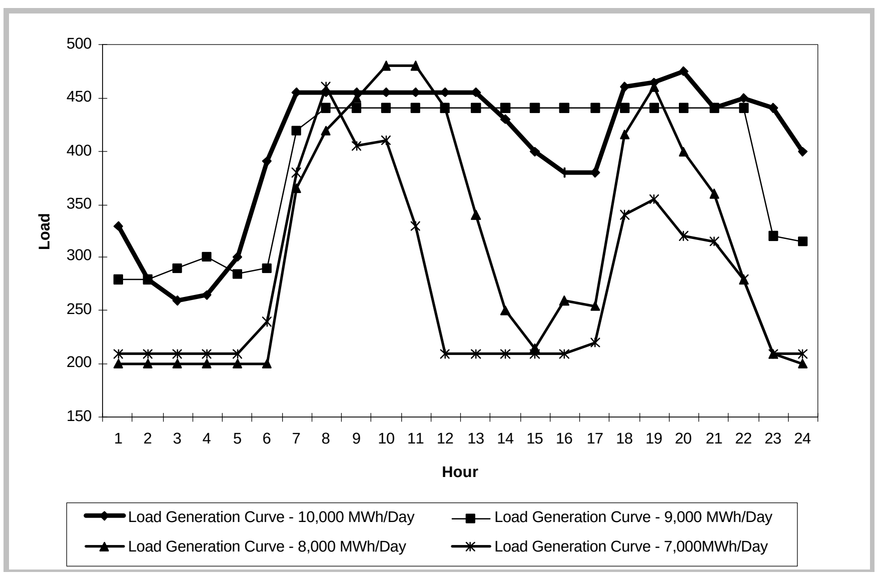

Figure 7. Typical daily load curves used as input to CBAS

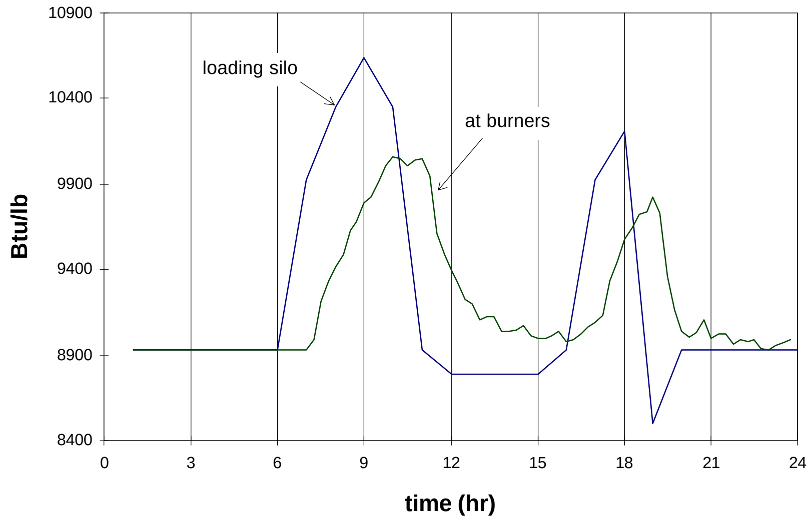

Figure 8. CBAS dynamic coal blend leads and lags the load curve to provide required energy content at the burners in real time

Conclusions

From the initial experience at Praxis' beta sites, the following conclusions have been drawn:

- Tracking various coals in the yard is necessary for successful dynamic blending.
- By correctly storing and analyzing information about each coal, effective blending can be carried out without addition of expensive mechanical systems.
- By understanding and modeling the flow patterns in the silos and stockpiles, blending schemes can be devised to:
  - ∗ Rationalize the use of available coals
  - ∗ Solve specific problems
  - ∗ Increase the use of cheaper fuels and gain fuel flexibility.
- CBAS is a real-time software system that provides optimal blending advice on-line to readily implement the blending scheme and accrue its substantial cost savings.

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